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International application number: PCT/US04/042880

International filing date: 17 December 2004 (17.12.2004)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/530,385
Filing date: 17 December 2003 (17.12.2003)

Date of receipt at the International Bureau: 24 January 2005 (24.01.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

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FILING DATE: ***December 17, 2003***
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This is a request f r filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EV 147307539 US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
HUI	WANG	FREMONT, CALIFORNIA

☐ *Additional inventors are being named on the ______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHODS AND APPARATUS FOR IMPROVING REMOVAL RATE UNIFORMITY DURING ELECTROPOLISHING

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ENCLOSED APPLICATION PARTS ***(check all that apply)***

☑ Specification *Number of Pages* 10
☑ Drawing(s) *Number of Sheets* 15
☑ Application Data Sheet. See 37 CFR 1.76
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METHODS AND APPARATUS FOR IMPROVING REMOVAL RATE UNIFORMITY DURING ELECTROPOLISHING

INTRODUCTION

The present invention relates generally to the methods and apparatus for improving removal rate uniformity during electropolishing.

SUMMARY OF INVENTION

One aspect of the present invention relates to an exemplary apparatus and processing method to control removal rate uniformity in electropolishing process. The exemplary apparatus includes a nozzle. The nozzle can be of a concave shape, a convex shape, a recess shape, an unsymmetrical shape, a statically adjustable recess shape, or dynamically adjustable recess shape nozzle.

In accordance with another aspect of the present invention, a dual electrode chuck is used to control removal rate uniformity in electropolishing process. One exemplary embodiment of the present invention includes a dual electrode chuck connected to a single power supply with dual switches. Another exemplary embodiment includes a dual electrode chuck connected to single power supply with dual switches and single resistor in electropolishing process. Alternative configuration of the present invention can include a dual electrode chuck connected to single power supply with a single variable resistor, a dual electrode chuck connected to dual power supplies with single switch, or a dual electrode chuck connected to dual power supplies with dual switches.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

In order to provide a more thorough understanding of the present invention, the following description sets forth numerous specific details, such as a specific material, parameters, and the like. It should be recognized, however, that such description is not intended as a limitation on

the scope of the present invention, but is instead provided to enable a more full and a more complete description of the exemplary embodiments.

Additionally, the subject matter of the present invention is particularly suited for use in connection with electroplating and/or electropolishing of semiconductor workpieces or wafers. As a result, exemplary embodiments of the present invention are described in that context. It should be recognized, however, that such description is not intended as a limitation on the use or applicability of the present invention. Rather, such description is provided to enable a more full and a more complete description of the exemplary embodiments.

New Nozzle Shape Design

Fig. 1 shows an electropolishing mechanism consists of wafer chuck 1002, wafer 1004, moving mechanism to rotate and laterally translate wafer chuck 1002, electrolyte nozzle 1010, moving mechanism 1012 to laterally translate nozzle 1010, and electrical power supply 1018 connecting with wafer 1004 and nozzle anode 1014. For a more detailed description of the electropolisher, see U.S. Letter Patent No. 6,395,152, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on July 2, 1999, the entire content of which is incorporated herein by reference. Also see U.S. Provisional Application Ser. No. 60/462,642, entitled METHODS AND APPARATUS FOR OPTIMIZING ELECTROPOLISHER, filed on April 14, 2003, the entire content of which is incorporated herein by reference, disclosing variety of nozzle shape designs to enhance removal rate profile of nozzle during electrical polishing process.

The removal rate profile of nozzle is related to the gap between nozzle 2010 and wafer 2004 as shown in Figs. 2A through 2D. As depicted in Fig. 2B, the removal rate profile is convex when the gap is small. As shown in Fig. 2C, the removal rate profile is nearly flat when the gap is medium size and, as shown in Fig. 2D, is concave when the gap is big. The gap is "small" when the gap is smaller or much smaller than diameter of nozzle 2010. The gap is "big" when the gap is bigger or much bigger than diameter of nozzle 2010.

In the present exemplary embodiment, the removal rate profile of nozzle can be changed without changing the gap size by inserting a metal showerhead 3016 inside the nozzle as shown in Figs. 3A and 3B. When the gap is a constant with wafer reasonably closed to nozzle, the removal profile is convex, as shown in Fig. 3A, if the showerhead is set to the same level to top of nozzle anode 3014. With reference now to Fig. 3A, the removal profile is nearly flat if the showerhead is set lower than top of nozzle anode 3014(i.e. H is small). As shown in Fig. 3C, the removal profile is concave if the showerhead is set much lower than top of nozzle anode 3014 (i.e. H is big).

With reference to Figs. 4A through 4F, the shape of showerhead 4016 can be flat (Fig. 4A), convex (Fig. 4B), concave (Fig. 4C), unsymmetrical (Fig. 4D), concave triangle (Fig. 4E), or convex triangle (Fig. 4F). The shape of showerhead 4016 can affect the electropolishing current distribution across nozzle 4010, thus affecting removal rate profile across nozzle 4010.

In order to improve removal rate uniformity across wafer, the removal rate profile of nozzle can vary dynamically by changing the gap between nozzle and wafer during the electropolishing process. More specifically, the gap can be changed by moving chuck (or nozzle) up and down during nozzle moving from center to edge of the wafer, or from edge to center of the wafer.

Alternatively as shown in Fig. 5, the removal rate profile of nozzle during the electropolishing process can vary by changing the position of showerhead 5016 relative to nozzle outer 5013. Nozzle outer 5013, nozzle inner 5014 and showerhead 5016 can be made of metal or alloy, such as stainless steel, Titanium or tantalum. More specifically, showerhead 5016, together with nozzle inner 5014, is automatically movable relative to nozzle outer 5013 during electropolishing process. The moving mechanism (not shown in Fig. 5) can be of motor, hydraulic piston, cylinder, or any other driving mechanism. Further, nozzle outer 5013 can be made of dielectrics or insulator, such as plastics or quartz.

<u>Dual Electrode Chuck</u>

In one exemplary aspect of a dual electrode chuck in accordance to the present invention, the chuck may include chuck top 6002, wafer 6004, inner seal 6118, outer seal 6119, insulating ring 6117, primary electrode 6115, and secondary electrode 6114. An exemplary dual electrode chuck that may be used to enhance the removal rate uniformity near edge of wafer during electropolishing process is described in U.S. Provisional Application Ser. No. 60/332,417, entitled ELECTROPOLISHING ASSEMBLY, filed on November 13, 2001; No. 60/372,567, entitled METHOD AND APPARATUS FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE, filed on April 14, 2002; and PCT patent application No. PCT/US02/36567, entitled ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS, filed on November 13, 2002, all of which are incorporated herein by reference in their entirety.

Primary and secondary electrodes are made of metal and alloys, such as stainless steel, Titanium, Tantalum, or Platinum. With reference now to Fig. 6, insulating ring 6117 is made of plastics such as PVC, PVDF, or Teflon, or rubber such as Vilton or silicon rubber. Primary electrode 6115 is isolated from secondary electrode 6114 by insulating ring 6117, inner seal 6118, and outer seal 6119. Primary electrode 6115 is connected to power supply through switch 6120, and secondary electrode 6114 is connected to power supply 6110 through switch 6122. The removal rate profile across wafer is shown in Fig. 7A. The switch 6120 is turn on and switch 6122 is turn off because when electrolyte reaches wafer surface, some of electrolyte will move across wafer to edge of wafer even nozzle is far from edge of wafer. These electrolytes also conduct a portion of electric current that goes back to the metal film on wafer and finally reaches electrode 6115, which can polish the metal film near the edge of wafer.

Another removal rate profile across wafer is shown in Fig. 7B when switch 6120 is turn off and switch 6122 is turn on. In this case, the electropolishing current goes through electrolyte and reaches secondary electrode 6114 when nozzle is far from the edge of wafer, thus no over-polishing occurs. Furthermore, with nozzle moves towards the edge of wafer, the polishing current is partially absorbed by secondary electrode 6114, causing under-polishing. With appropriate timing to control the on/off sequence of switches 6120 and 6122, the removal rate

profile can be straight near the edge of wafer. More specifically, assuming that the nozzle polishes from center to the edge of wafer, on/off sequence can be described as follows:

(The sequence can be reversed when the nozzle polishes from edge to center of wafer.)

Sequence 1

When nozzle is far from the edge of wafer, turn on switch 6122 and turn off switch 6120.
When nozzle moves near to the edge of wafer, turn off switch 6122 with turn on 6120.
When nozzle moves over the edge of wafer, turn off both switches 6122 and 6120.

Sequence 2

When nozzle is far from the edge of wafer, turn on switch 6122 and turn off switch 6120.
When nozzle moves near to the edge of wafer, turn on both switches 6122 and 6120.
When nozzle moves to the edge of wafer, turn off switch 6122 with switch 6120 on.
When nozzle moves over the edge of wafer, turn off both switches 6122 and 6120.

It should be mentioned that the polishing current can vary when nozzle is close to the edge of wafer in order to further fine-tune the removal rate profile near the edge. The current adjustment can be made based on the removal rate profile measured on the polished wafer. If the removal rate on edge is high, then reduce the polishing current as the nozzle moves to edge of the wafer; if the removal rate on edge of wafer is low, then increase the polishing current as the nozzle moves to edge of wafer.

Fig. 8 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 8 is similar to that shown in Fig. 6 except that only one switch 8120 and one additional power supply (or secondary power supply) 8111 are connected between primary electrode 8115 and main power supply 8110. Secondary electrode 8114 is directly connected to main power supply 8110. The primary and secondary power supply can be operated at either constant current mode or constant voltage mode. The detail operation sequence is described as follows:

Sequence 3

When nozzle is far from the edge of wafer, turn off switch 8120. When nozzle moves near to the edge of wafer, turn on switch 8120 with appropriate voltage or current output from power supply 8111. If the power supply 8111 is operated at the constant current mode, the current set can be made based on post-removal rate profile near the edge of wafer. When removal rate profile at the edge of the wafer is high, reduce the current output from power supply 8111. A similar adjustment can be performed if power supply 8111 is operated at constant voltage mode. When nozzle moves over the edge of wafer, turn off both primary and secondary power supplies 8111 and 8110.

Fig. 9 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 9 is similar to that shown in Fig. 6 except that only one switch 9122 and one additional power supply (or secondary power supply) 9112 are connected between secondary electrode 9114 and main power supply 9110. Primary electrode 9114 is directly connected to main power supply 9110. The primary and secondary power supply can be operated at either constant current mode or constant voltage mode. The detail operation sequence is described as follows:

Sequence 4

When nozzle is a distance away from the edge of wafer, turn on switch 9112 with appropriate voltage or current set at secondary power supply 9112 so that the majority of the polishing current flow can through secondary electrode 9114. When nozzle moves near to the edge of wafer, reduce voltage or current output from secondary power supply 9112 so that certain portions of the polishing current flow through electrode 9115. If the power supply 9112 is operated at the constant current mode, the current set can be made based on post-removal rate profile near the edge of wafer. When removal rate profile at the edge of wafer is high, increase the current flowing through electrode 9114 by adjusting output of power supply 9112. A similar adjustment can be performed if power supply 9112 is operated at constant voltage mode. When nozzle moves over the edge of wafer, turn off both primary and secondary power supplies 9112 and 9110.

Fig. 10 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 10 is similar to that shown in Fig. 6 except that an additional resistor 10123 is inserted between switch 10120 and power supply 10110. Resistor 10123 can be either a constant resistor or adjustable resistor. The detail operation sequence is described as follows:

Sequence 5

When nozzle is a distance away from the edge of wafer, turn on switch 10122 and turn off switch 10120 so that the majority of the polishing current flows through secondary electrode 10114; and when nozzle is moved near to edge of wafer, turn on switch 10120 with appropriate value of resistor 10123 so that certain portions of the polishing current flow through electrode 10115. The value of resistor 10123 can be adjusted or selected based on post removal rate profile near the edge of wafer. When removal rate profile at edge of wafer is high, reduce the current flowing through electrode 10115 by increasing the value of resistor 10123. When nozzle moves over the edge of wafer, turn off both switches 10122 and 10120.

Fig. 11 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 11 is similar to that shown in Fig. 6 except that additional resistor 11125 is inserted between switch 11122 and power supply 11110. Resistor 11125 can be either a constant resistor or adjustable resistor. The detail operation sequence is described as follows:

Sequence 6

When nozzle is a distance away from the edge of wafer, turn on switch 11122 and turn off switch 11120 so that the majority of the polishing current flows through secondary electrode 11114. When nozzle moves near to the edge of wafer, turn on switch 11120 with appropriate value of resistor 11125 so that certain portions of the polishing current flow through electrode 11115. The value of resistor 11125 can be adjusted or selected based on post-removal rate profile near the edge of wafer. When removal rate profile at the edge of wafer is high, reduce the

current flowing through electrode 11115 by reducing the value of resistor 11125. When nozzle moves over the edge of wafer, turn off both switches 11122 and 11120.

Fig. 12 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 12 is similar to that shown in Fig. 6 except that secondary electrode 12122 is partially embedded in the insulating ring 12117. The operation sequence is similar to sequences 1 and 2 as depicted in Fig. 6.

Fig. 13 shows another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 13 is similar to that shown in Fig. 12 except that primary electrode 13115 and secondary electrode 13116 are connected to power supply 13110 through a three way adjustable resistor 113127. The detail operation sequence is described as follows:

Sequence 7

When nozzle is a distance away from the edge of wafer, set three way adjustable resistor 13127 to make the resistance between secondary electrode 13116 and power supply to be a minimum value so that the majority of the polishing current flows through secondary electrode 13116. When nozzle moves near to the edge of wafer, set three way adjustable resistor by increasing the resistance between secondary electrode 13116 and power supply 13110 so that certain portions of the polishing current flow through electrode 13115. The ratio of three-way resistor 13127 can be adjusted or selected based on post-removal rate profile near the edge of wafer. When removal rate profile at the edge of wafer is high, reduce the current flowing through electrode 13115 by increasing the value of resistance between primary electrode 13115 and power supply 13110. When nozzle moves over the edge of wafer, turn off power supply 13110 (on/off switch is not shown in Fig. 13).

Fig. 14 shows yet another exemplary embodiment of a dual electrode chuck in accordance to the present invention. The dual electrode chuck shown in Fig. 14 is similar to that shown in Fig. 6 except that each of primary and secondary electrodes is connected with an

independent power supply 14110 and 14111 through independent switches 14120 and 14122. The detail operation sequence is described as follows:

Sequence 8

When nozzle is a distance away from the edge of the wafer, turn on switch 14122 and turn off switch 14120 so that all the polishing current flows through secondary electrode 14116. When nozzle moves near to the edge of the wafer, turn on switch 14120 with appropriate output set for power supply 14110 and power supply 14111 so that certain portions of the polishing current flow through electrode 14115. The values of output of power supply 14110 and power supply 14111 can be adjusted or selected based on post-removal rate profile near the edge of wafer. When removal rate profile at the edge of wafer is high, reduce the current flowing through electrode 14115 by reducing the value of output from power supply 14110. When nozzle moves over the edge of wafer, turn off both switches 14122 and 14120.

Sequence 9

When nozzle is a distance away from the edge of the wafer, turn on switch 14122 and turn off switch 14120 so that all the polishing current flows through secondary electrode 14116. When nozzle moves near to the edge of the wafer, turn off switch 14122 turn on switch 14120 with appropriate output set for power supply 14110 so that appropriate polishing current flow through electrode 14115. The values of output of power supply 14110 can be adjusted or selected based on post removal rate profile near the edge of wafer. When removal rate profile at edge of wafer is high, reduce the current flowing through electrode 14115 by reducing the value of output from power supply 14110. When nozzle moves over the edge of wafer, turn off switch 14120.

All present invention disclosed herein can be used in variety of electropolishing mechanisms as shown in Fig. 15A to 15F. In general, both nozzle 15032 and wafer chuck 15020 can be stationary or moveable, and the wafer surface can be face up, or face down, or face side. The following table 1 summary the detail features:

Table 1. Variety of electropolishing mechanism

	Fig. 15 A	Fig. 15 B	Fig. 15 C	Fig. 15 D	Fig. 15 E	Fig. 15 F
Stationary Chuck				Yes	Yes	Yes
Movable Nozzle				Yes	Yes	Yes
Movable Chuck	Yes	Yes	Yes			
Stationary Nozzle	Yes	Yes	Yes			
Chuck Face	Side	Down	Up	Side	Down	Up

Although the exemplary methods and systems used to improve removal rate uniformity during electropolishing have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

The above detailed description of various devices, methods, and systems is provided to illustrate exemplary embodiments and is not intended to be limiting. It will be apparent to those skilled in the art that numerous modifications and variations within the scope of the present inventions are possible. Therefore, the present invention should not be construed as being limited to the specific forms shown in the drawings and described above.

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Filed: Herewith
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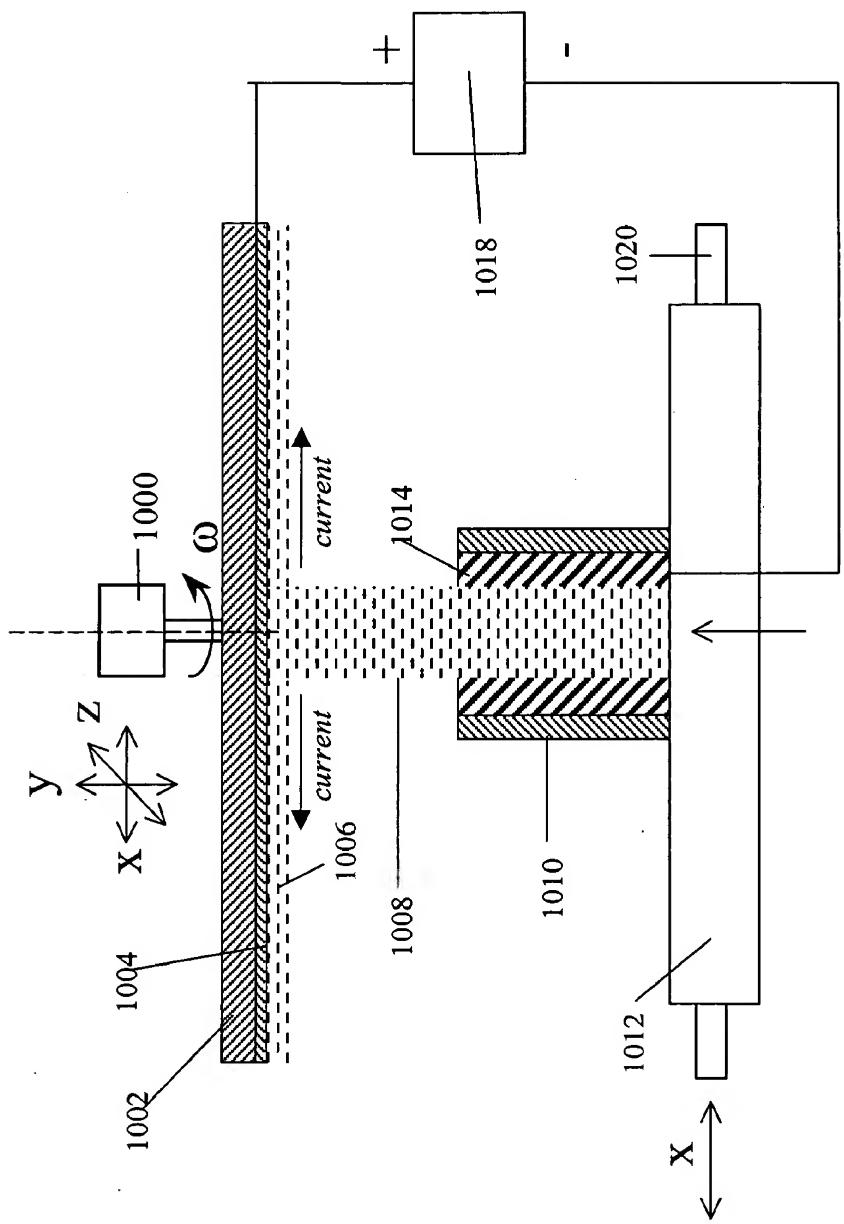

Fig. 1

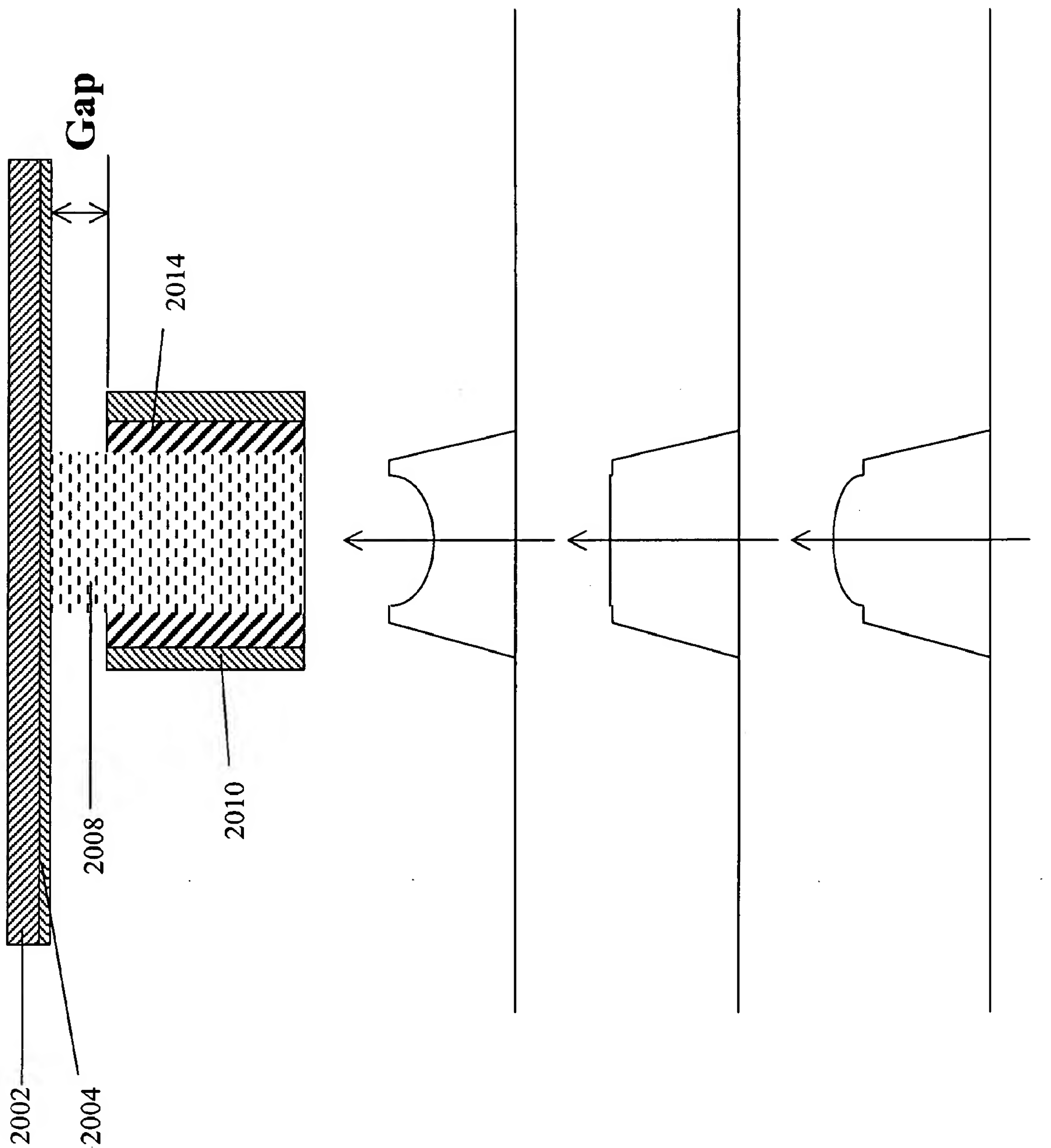

Fig. 2A

Fig. 2B

Fig. 2C

Fig. 2D

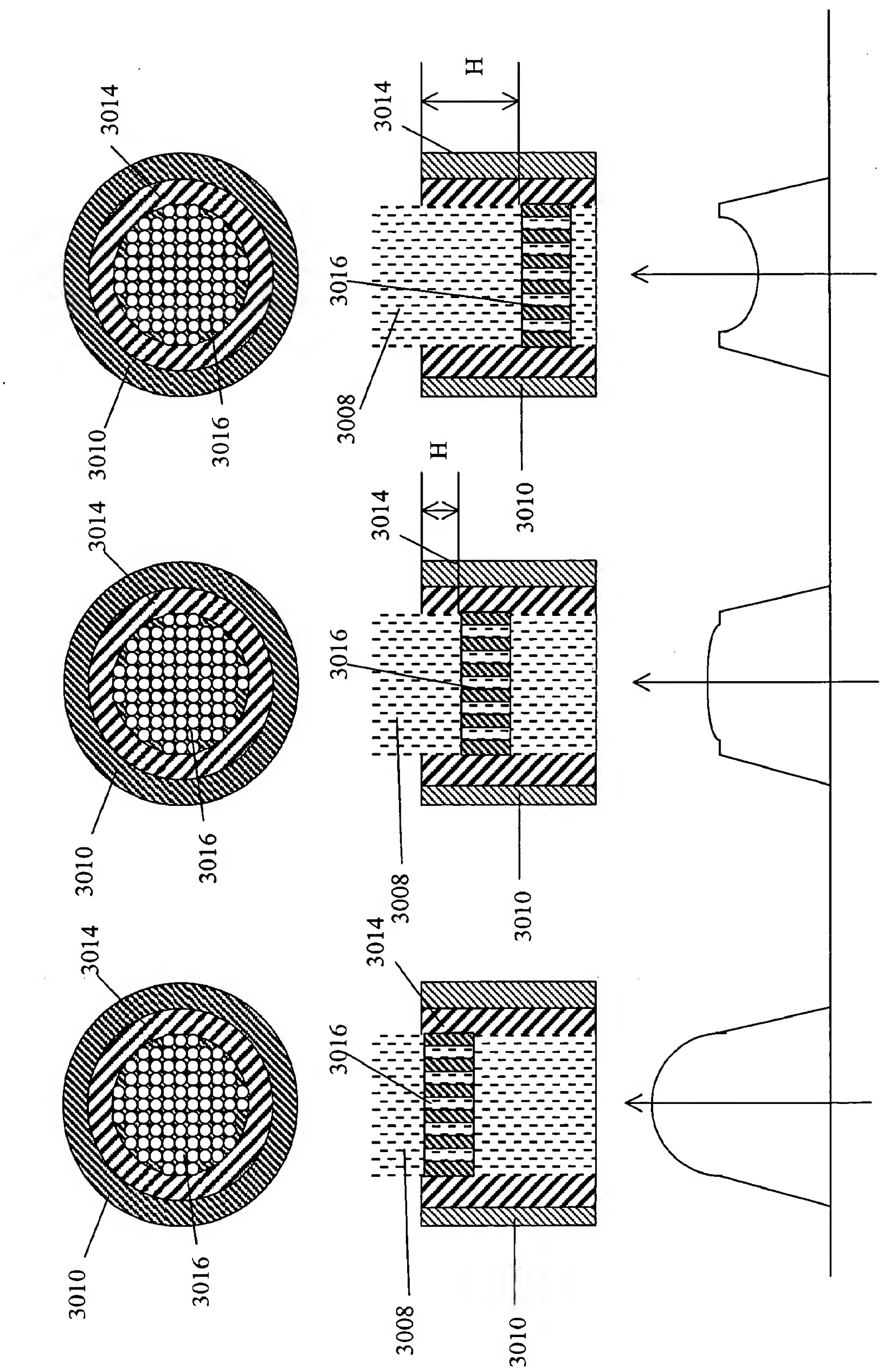

Fig. 3A

Fig. 3B

Fig. 3C

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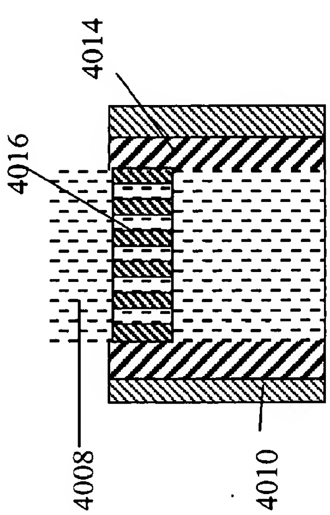


Fig. 4A

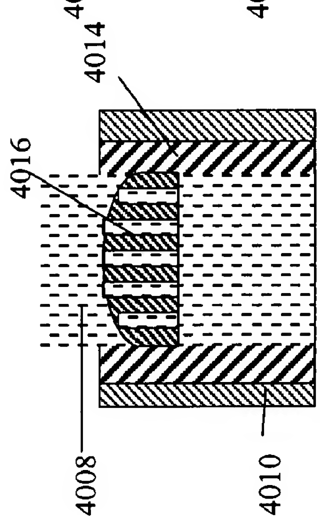


Fig. 4B

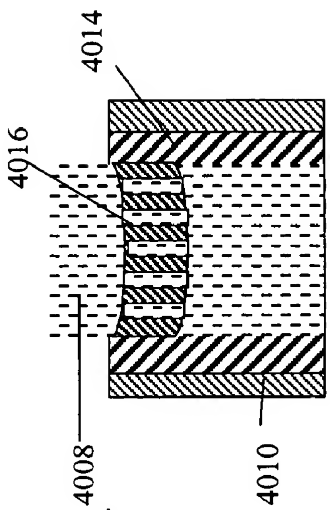


Fig. 4C

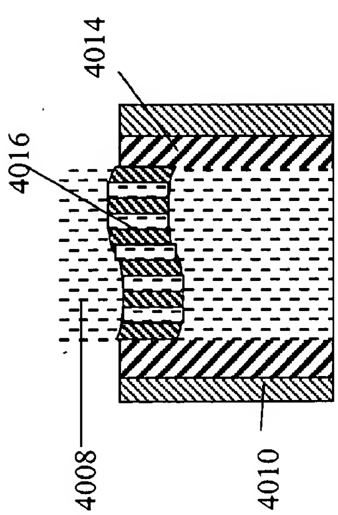


Fig. 4D

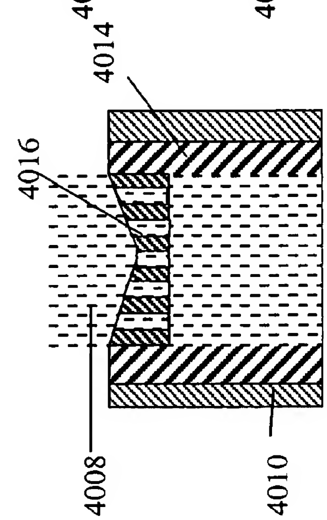


Fig. 4E

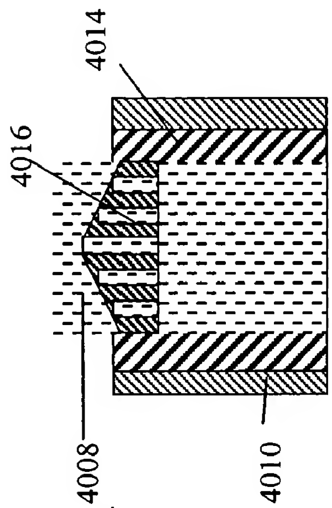
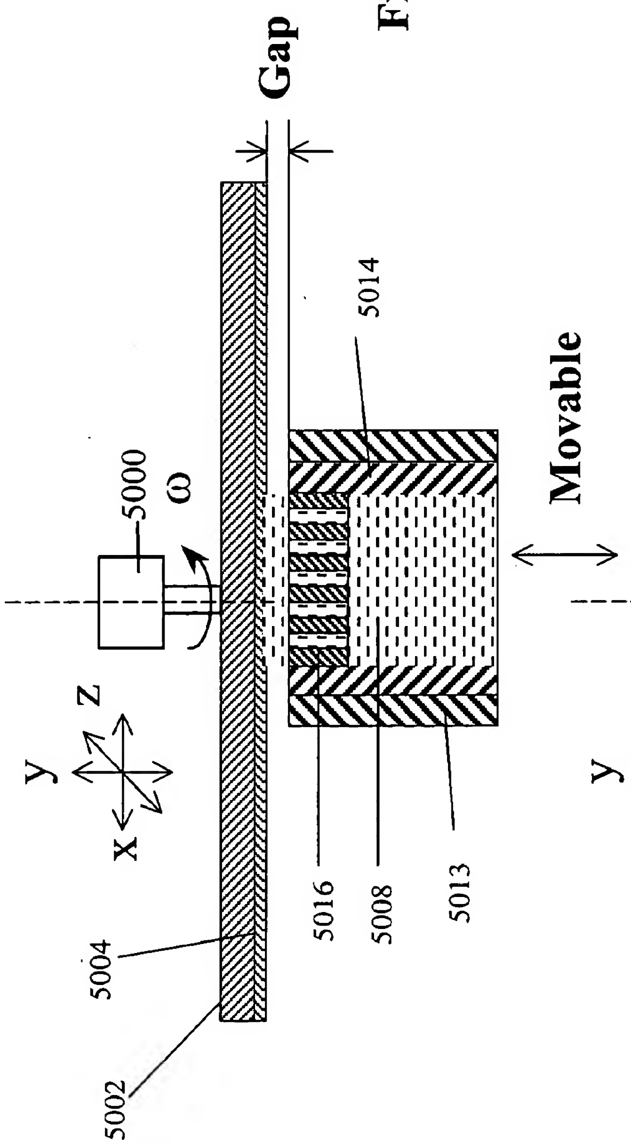


Fig. 4F


Gap
5014
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5016
5008
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5004
5002

Fig. 5A

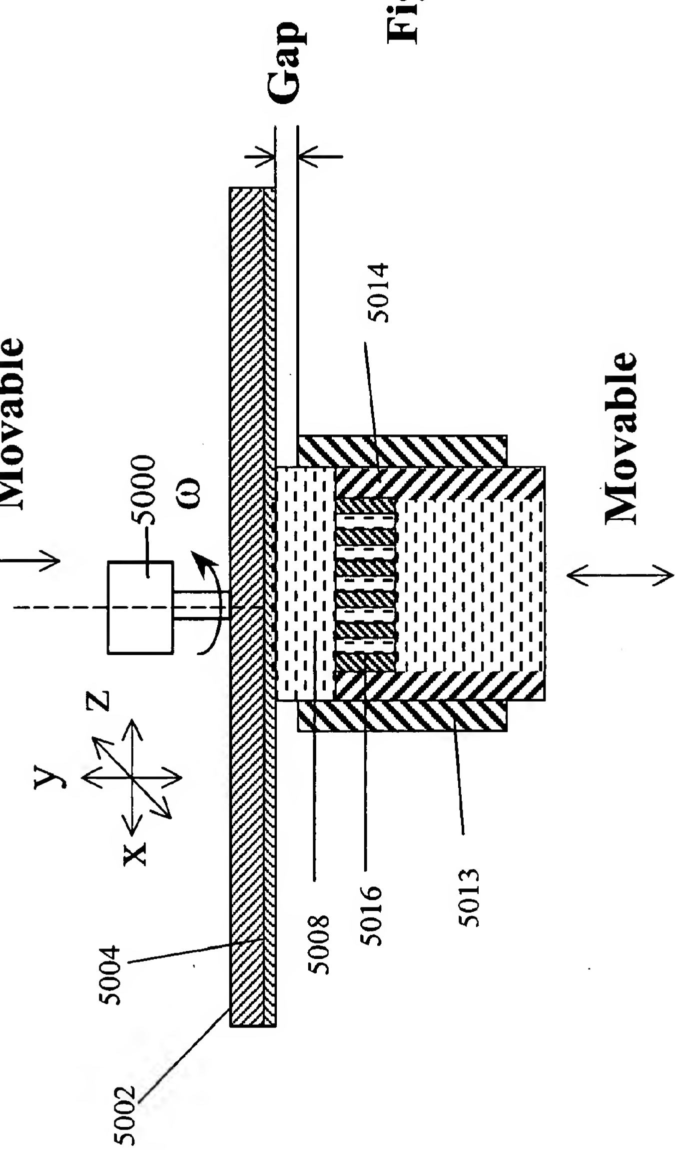
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Fig. 5B

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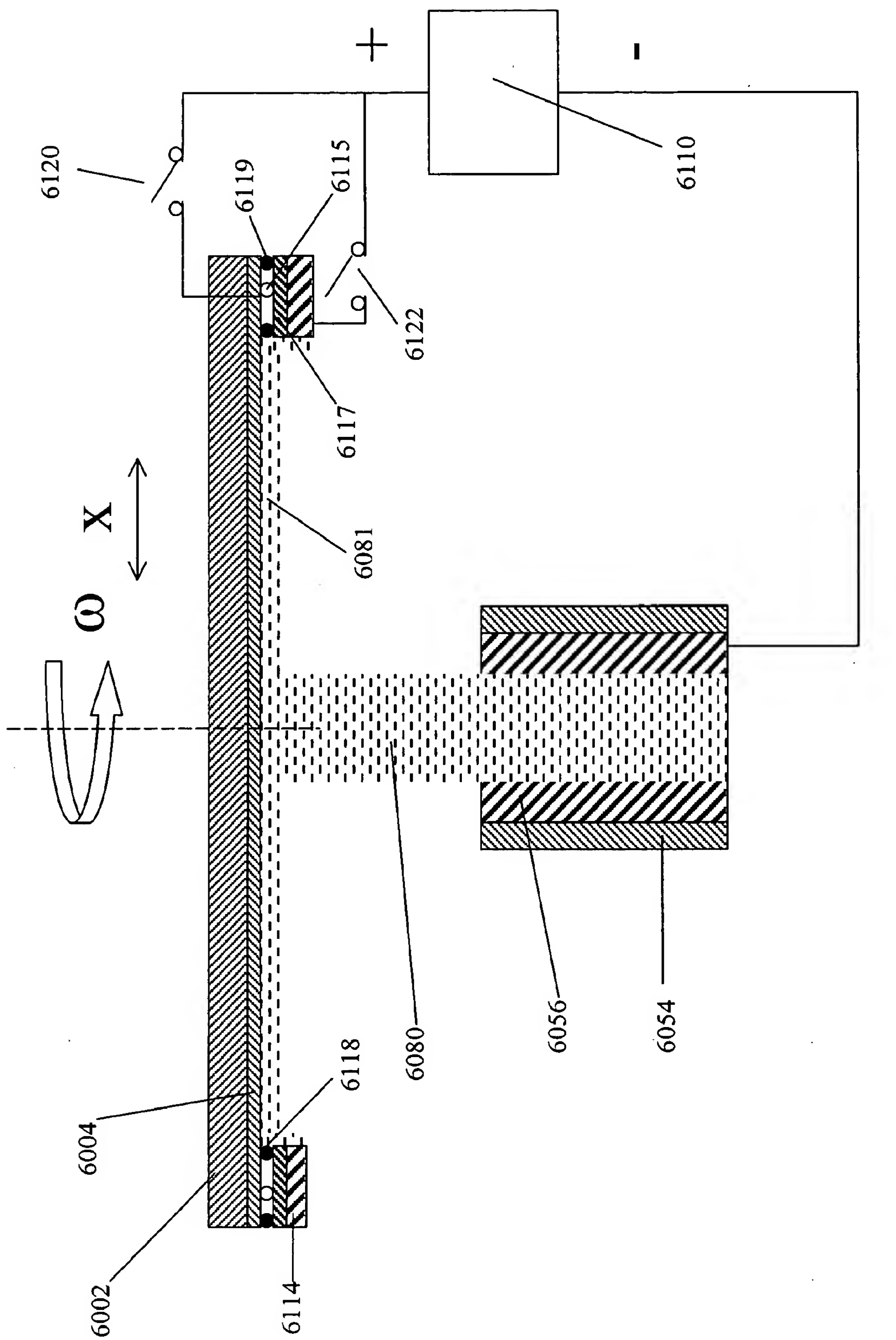

Fig. 6

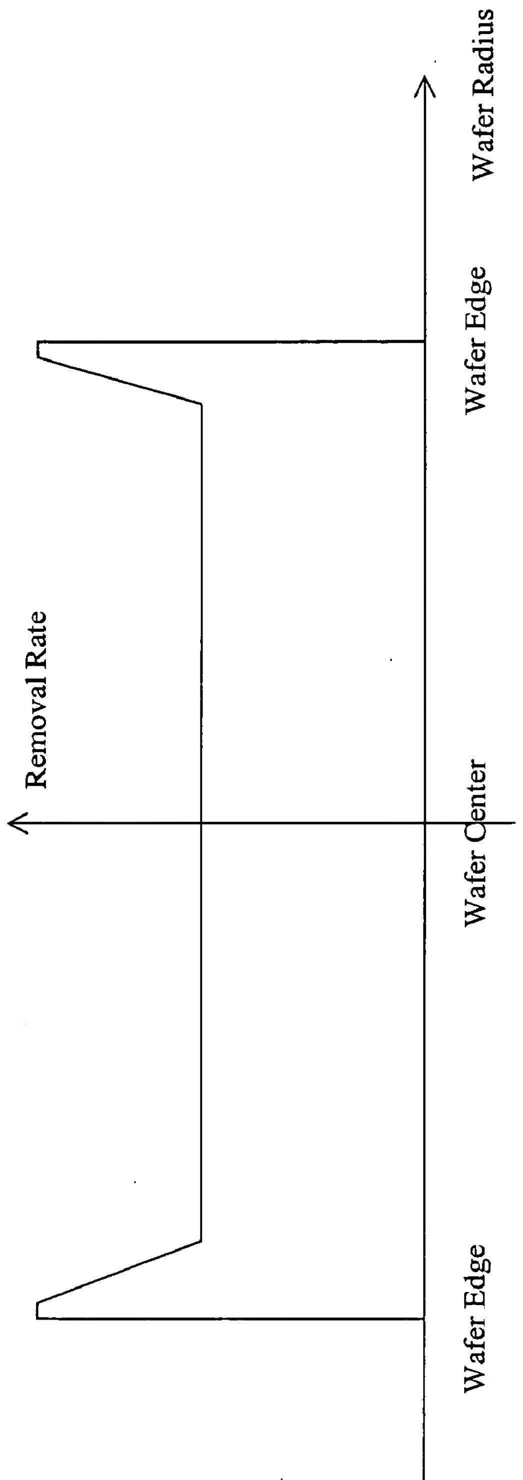
Removal Rate
Wafer Radius
Wafer Edge
Wafer Center
Wafer Edge

Fig. 7A

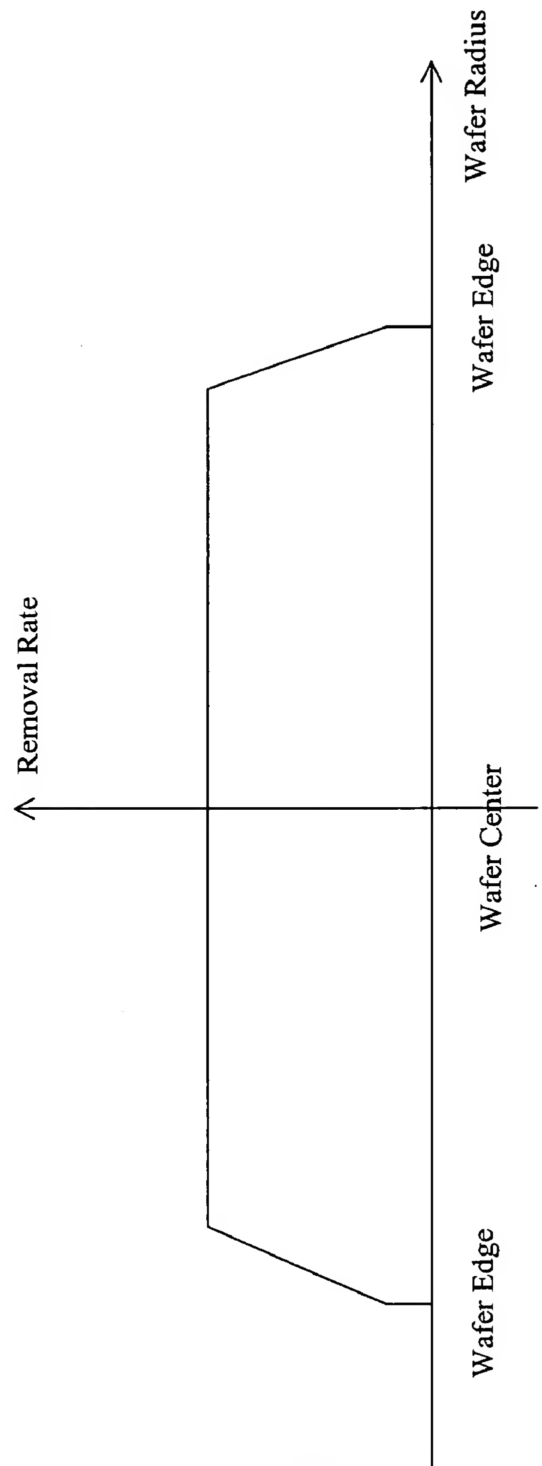
Removal Rate
Wafer Radius
Wafer Edge
Wafer Center
Wafer Edge

Fig. 7B

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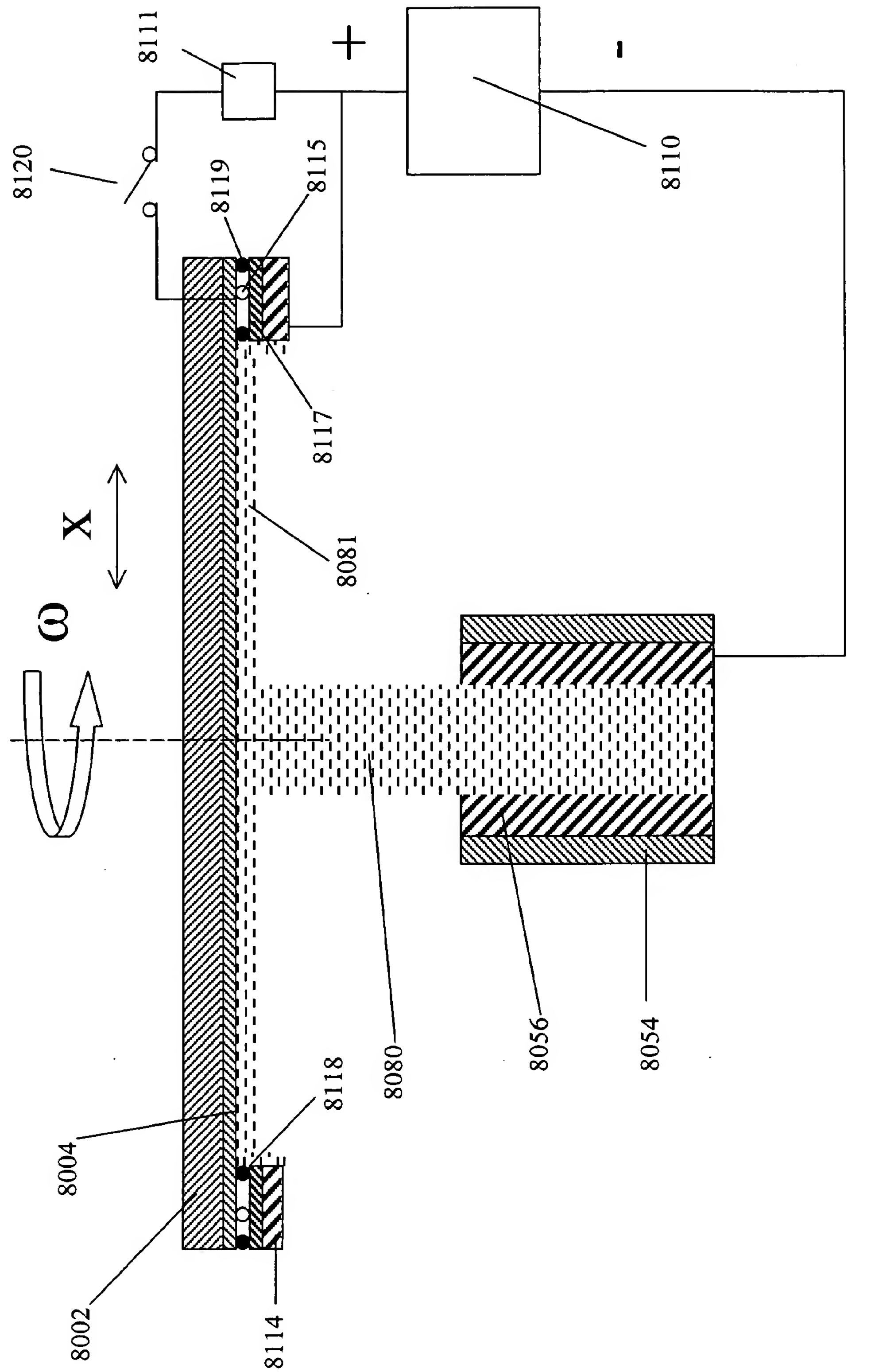

Fig. 8

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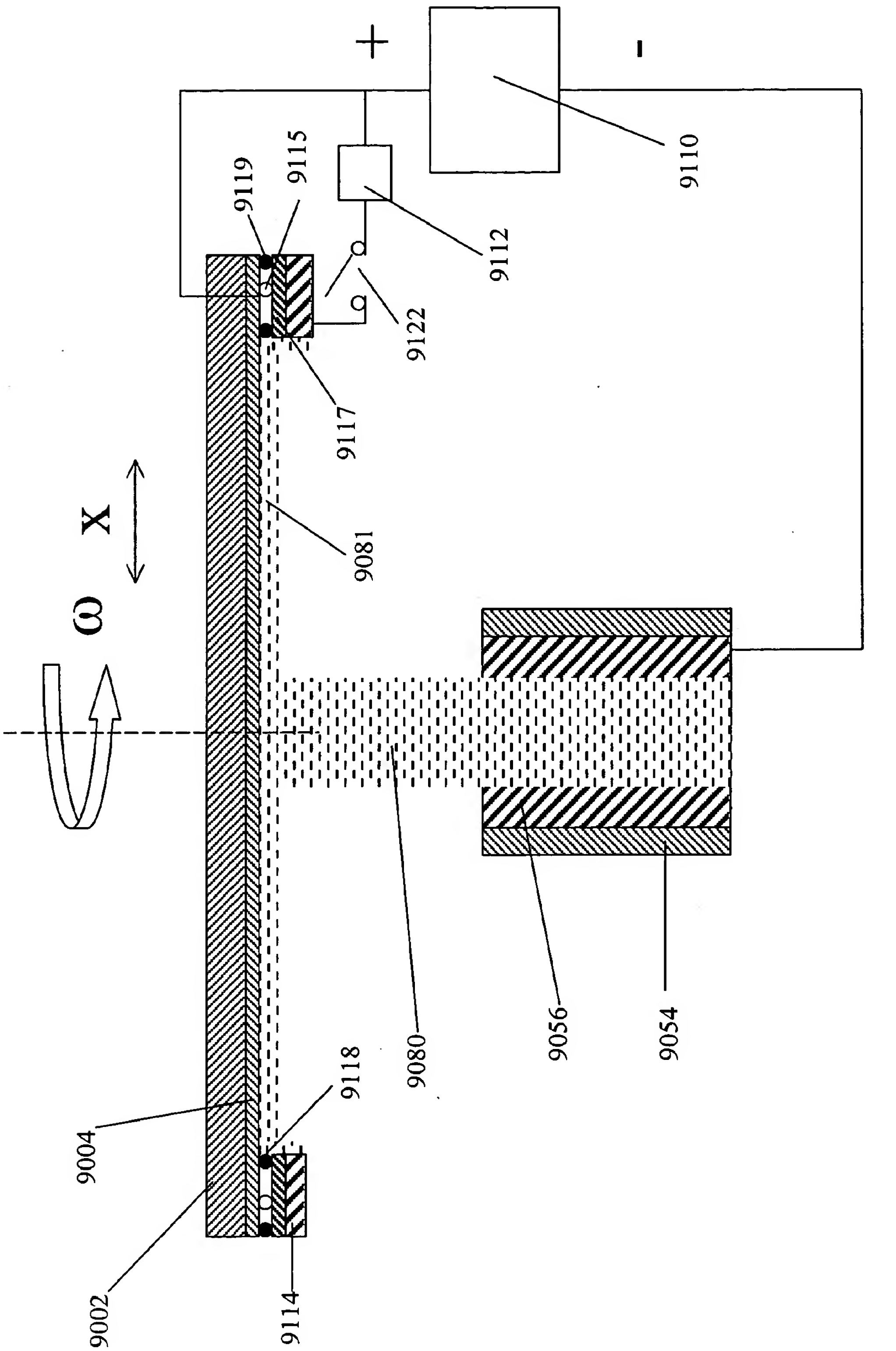

Fig. 9

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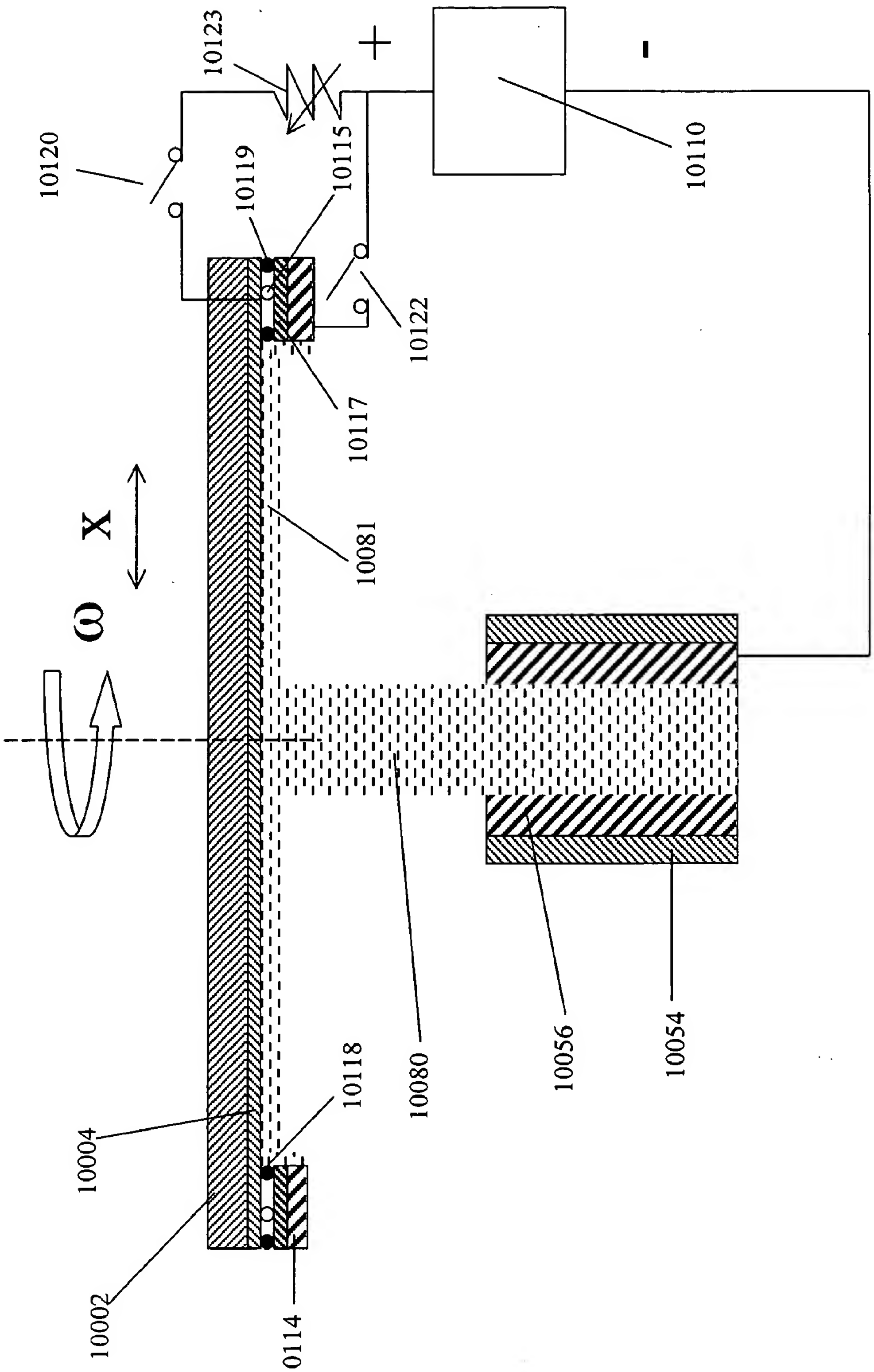

Fig. 10

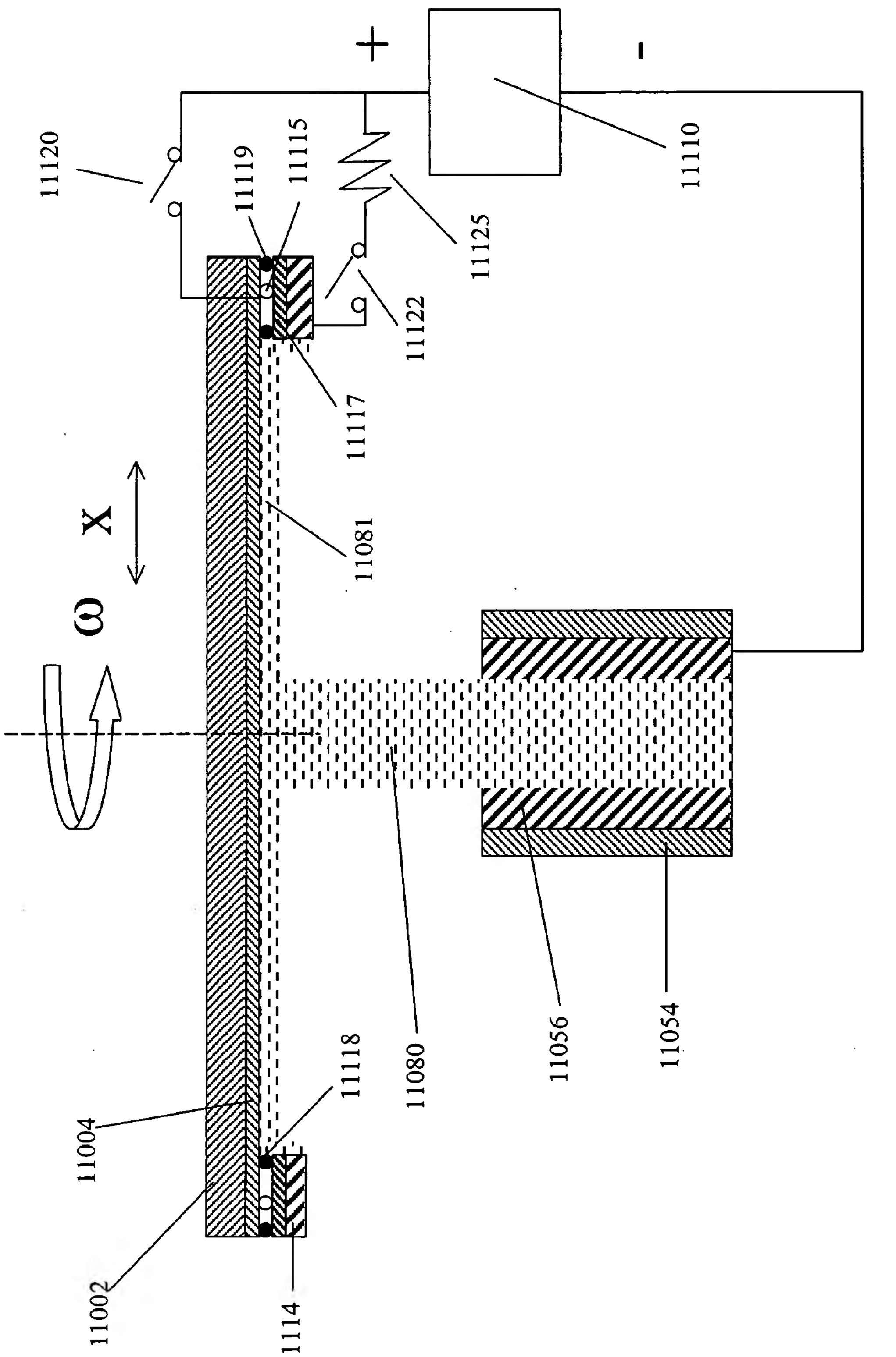
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Fig. 11

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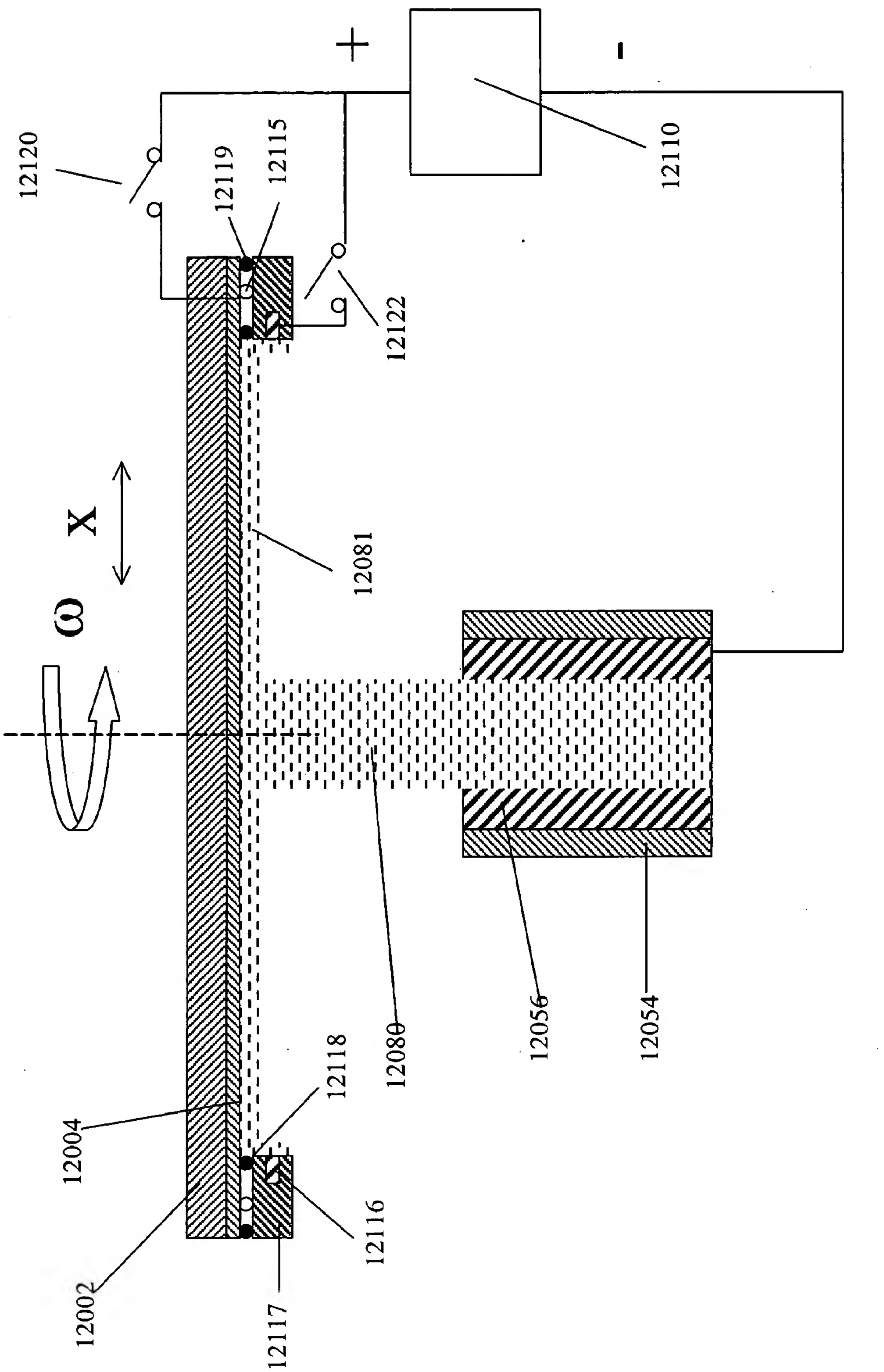

Fig. 12

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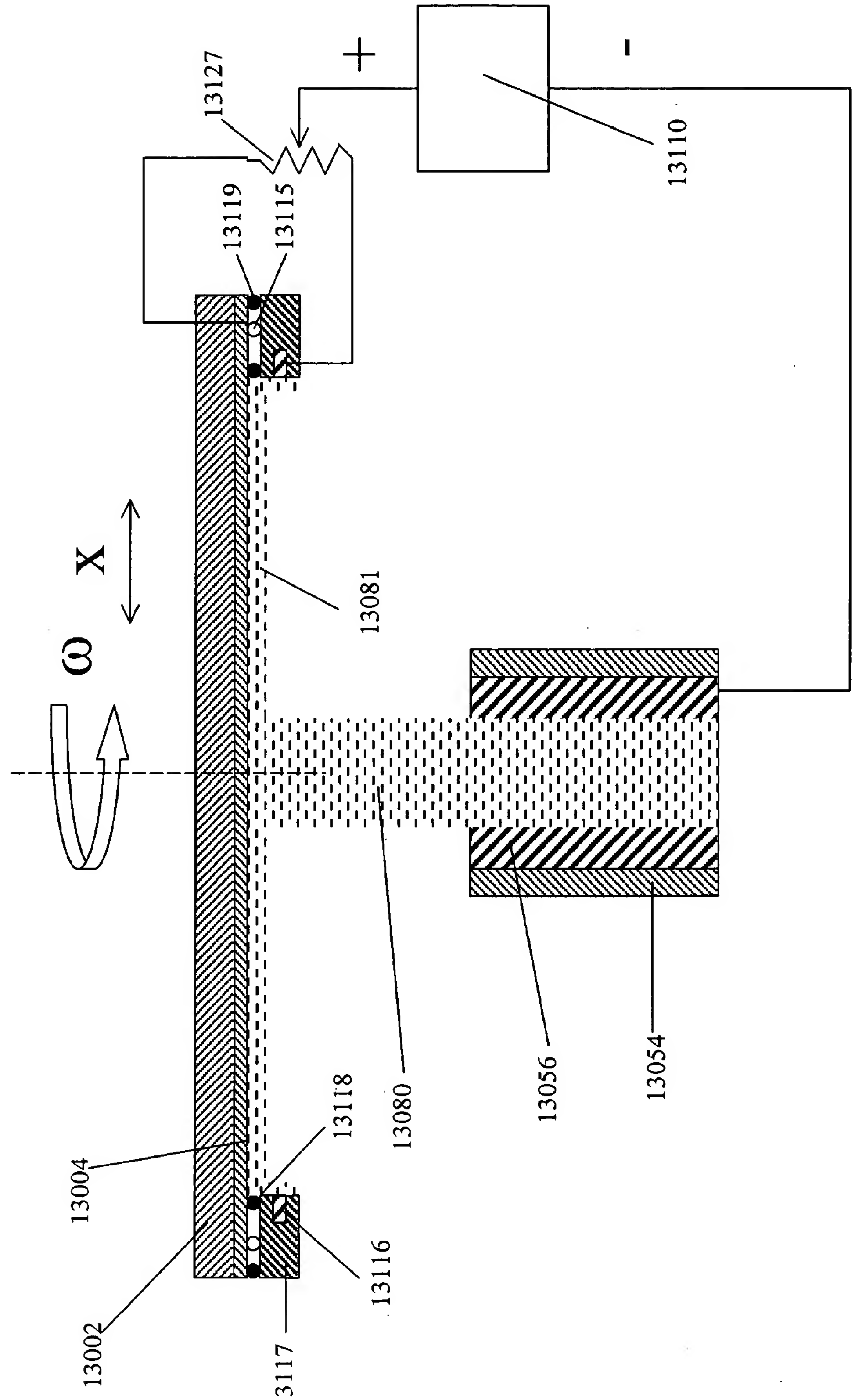

Fig. 13

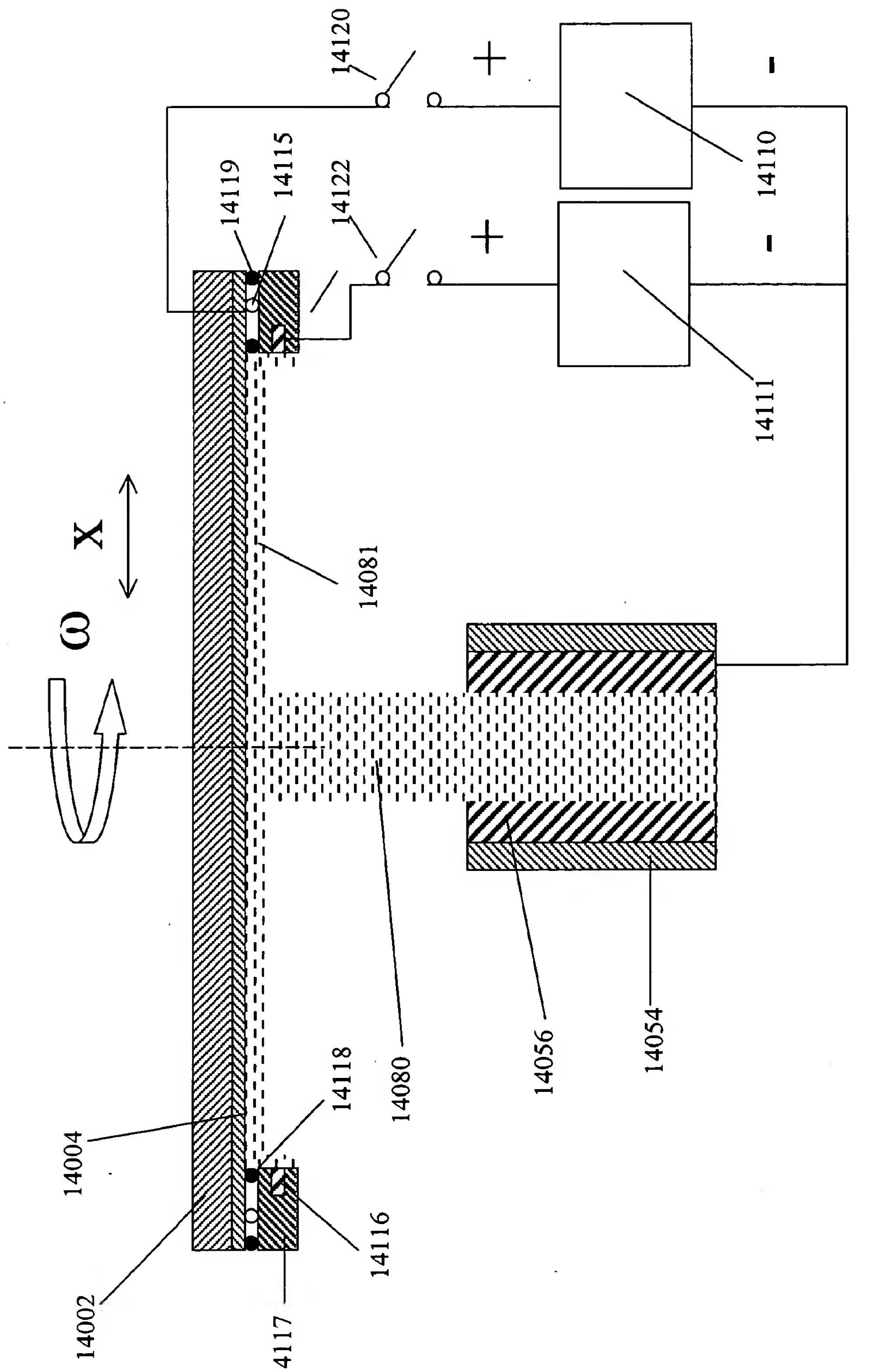
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Fig. 14

Title: Methods and Apparatus for Improving Removal Rate Uniformity During Electropolishing
Inventor: Hui WANG
Filed: Herewith
Sheet 15 of 15

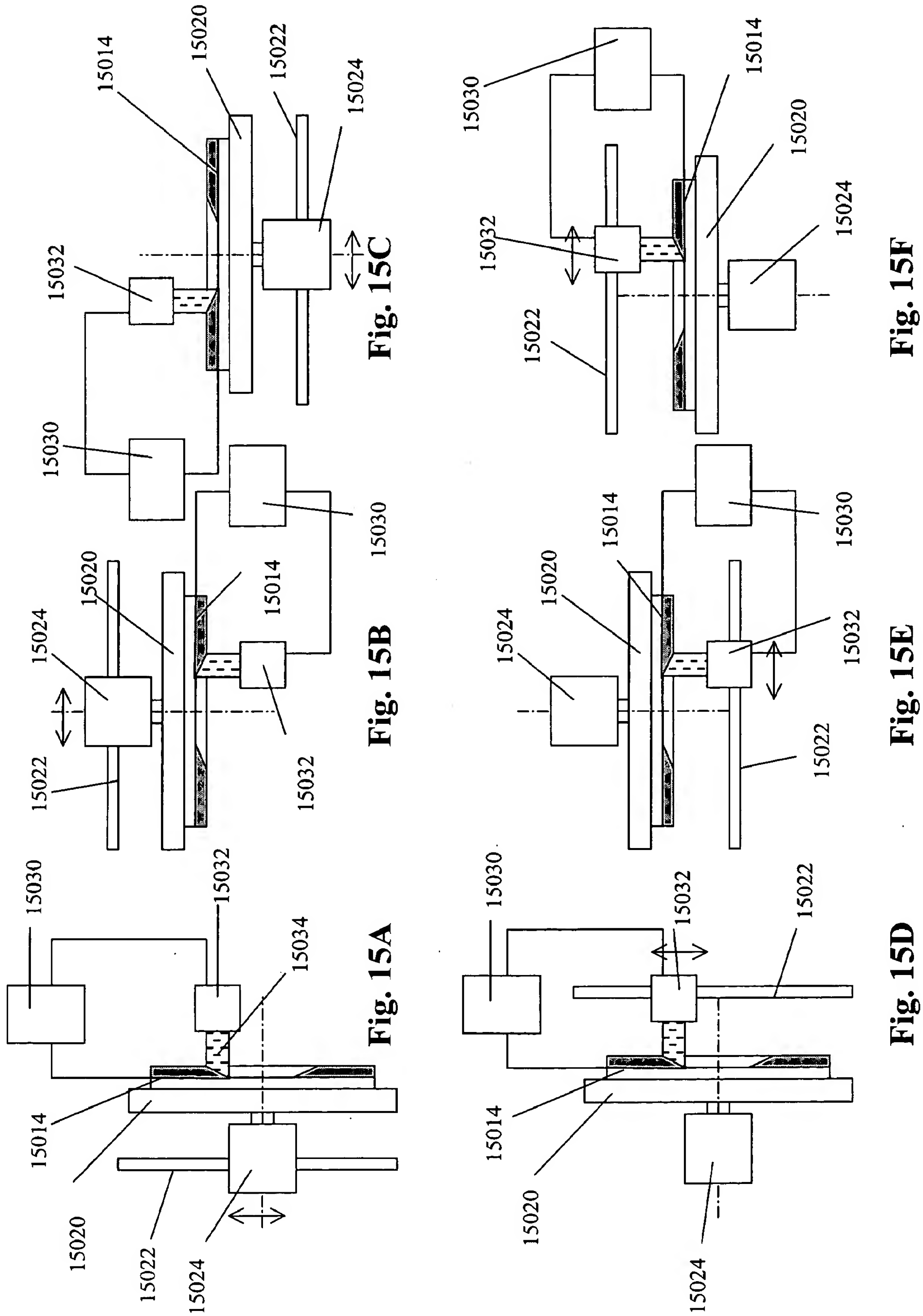

Fig. 15A

Fig. 15B

Fig. 15C

Fig. 15D

Fig. 15E

Fig. 15F

Application Data She t

Application Information

Application Type::	Provisional
Subject Matter::	Utility
Suggested classification::	
Suggested Group Art Unit::	
CD-ROM or CD-R?::	
Number of CD disks::	
Number of copies of CDs::	
Sequence submission?::	
Computer Readable Form (CRF)?::	
Number of copies of CRF::	
Title::	Methods and Apparatus for Improving Removal Rate Uniformity During Electropolishing
Attorney Docket Number::	
Request for Early Publication?::	
Request for Non-Publication?::	
Suggested Drawing Figure::	
Total Drawing Sheets::	15
Small Entity?::	Yes
Petition included?::	
Petition Type::	

Applicant Information

Applicant Authority Type::	Inventor
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Middle Name::	
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Representative Information

Representative Designation::	Registration number::	Name::
Primary	44417	Peter J. Yim

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::

Foreign Priority Information

Country::	Application number::	Filing Date::	Priority Claimed::

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